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SEAMLESS COLLAPSIBLE FUEL TANKS. Phase

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Final Report: Phase I

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A tubular fabric has been woven to make two 23 x 17 foot pillow tanks. A nitrile coating which could be applied as an aqueous latex was developed. The fabric will be coated and the tanks fabricated in Phase II of this report.

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Preface

The work described herein comprised Phase I of Contract No. DAAK70-80-C-0045, issued by MERADCOM, Fort Belvoir, VA to Albany International Research Co., Dedham, MA. Charles Browne was the Contracting Officer's Representative responsible for the technical monitoring of the work. Senior staff at Albany International Research Co. who were responsible for the work were Norman J. Abbott, Associate Director, Robert E. Erlandson and Robert E. Sebring, Senior Research Associates. Fabric weaving was done at Albany International Felt Division, Albany NY under the superivision of Eric Romanski, Senior Engineer.

Seamless Collapsible Fuel Tanks

Final Report: Phase I

Contract No. DAAK70-80-C-0045

Introduction

Pillow tanks are used for storing fuel in isolated locations, or as an auxiliary to more permanent installations. They are currently made by bonding together panels of coated fabric, and can be folded when empty for transportation by truck or helicopter. Standard storage capacities range from 3000 to more than 50,000 gallons of fuel, and "lay-flat" dimensions range from 14 x 14 feet to 25 x 60 feet.

The fabric from which they are made is woven on conventional textile looms to widths of not more than about 6 feet. A typical fabric would be made from 840 denier high tenacity nylon yarn, woven 28 ends x 28 picks per inch in a plain or basket weave. The fabric is then coated both sides with an appropriate fuel-resistant compound, usually a nitrile or a polyurethane, and the tank fabricated from strips cut to the required dimensions.

Because the tanks are larger than the maximum fabric width which can be woven on conventional textile looms, longitudinal seams must be used to join adjacent strips of fabric. The seams are formed by using an appropriate adhesive with or without the assistance of ultrasonic or dielectric heating. This forms seams which are originally as strong as the fabric itself. Nevertheless, the useful lifetime of a tank is commonly limited by failure of the seams, primarily along the top of the tank, presumably as a result of a degradation due to fuel and weathering effects, and prolonged high stress at elevated temperatures or other use stresses. Consequently, tanks often have to be discarded before the fabric itself has reached the end of its useful life.

In recognition of this deficiency in current pillow tank design, MERADCOM undertook to explore the feasibility of using a wide tubular woven fabric which would eliminate all but two end seams in the tank.

Tubular Weaving Technology

The interlacing pattern in a woven fabric is determined by the manner in which the warp yarns are threaded into the loom heddles (metal strips, one per warp yarn, carrying an eye through which the yarn is threaded), and the order in which the harnesses, carrying the heddles, are raised and lowered. Figure 1 shows the warp yarns as numbered circles, and the manner in which the warp sheds, through which the filling yarn is to be passed, are formed to make a single layer plain woven fabric. It is apparent that this can be done with two harnesses, one carrying the heddles through which the odd-numbered yarns are threaded, and the other those through which the even-numbered yarns are threaded.

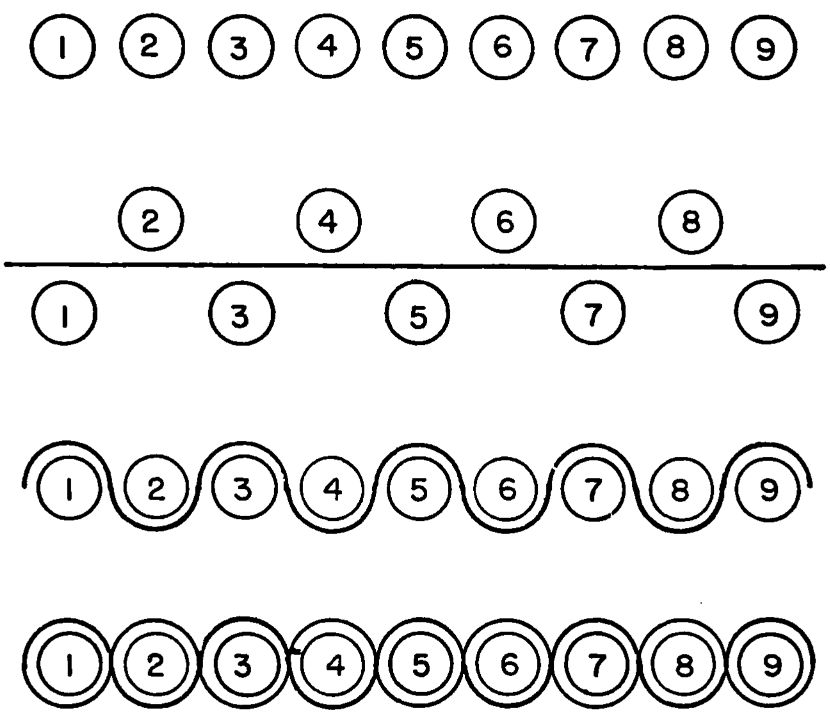

Figure 1. Single Layer Plain Woven Fabric

Weaving of a tubular plain woven fabric is illustrated in Figure 2. This requires four heddles, one controlling yarns 2 and 6, one for 4 and 8, one for 3 and 7, and one for 1,. 5, and 9. As shown in Figure 2, yarns 4 and 8 are raised first, then all except 3 and 7, then 2 and 6, then all except 1, 5 and 9, and then the cycle is repeated. In this way, two layers

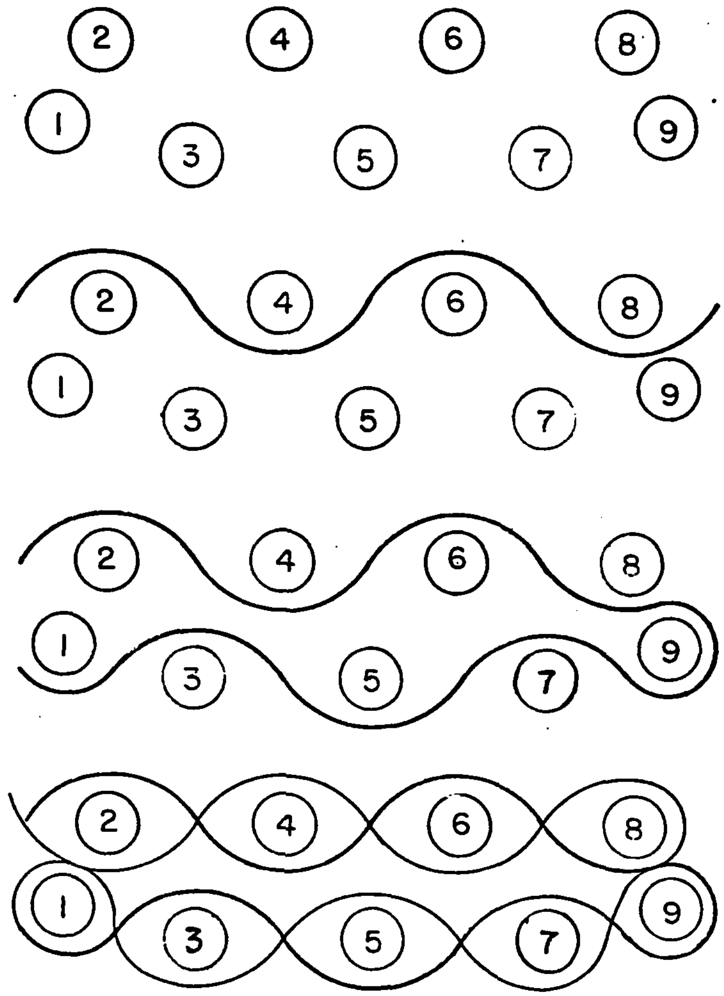

Figure 2. Tubular Plain Woven Fabric

of plain woven fabric are formed, connected together at either edge by the filling yarns which pass consecutively from top layer to bottom layer and back to the top layer. Clearly, the process is, in principle, no more complicated than weaving a single layer fabric, except that a special weaver's skill is required to adjust and control the loom operation so as to minimize or eliminate any discontinuity at the two edge turnaround points.

Narrow tubular woven fabrics are a common article of commerce. So, in fact, are very wide tubular fabrics which are used as endless, seamless belts on paper machines, where the filling direction of the fabric becomes the machine direction of the felt. The wide looms which make these fabrics do not exist in the conventional textile industry, but are common in mills devoted to the manufacture of what is called papermachine clothing. The

Felt Division of Albany International Corp. makes tubular fabric on looms in widths between 2-1/2 meters (8 feet) and 27-1/2 meters (90 feet). Since this range is sufficient to cover even the largest collapsible tanks currently under consideration, MERADCOM contracted with Albany International Research Co. to explore the use of these looms to make fabric for seamless pillow tanks. Of course, seamed closures will have to be made at the two open ends of the tube.

The initial request was to manufacture two prototype 3000 gallon tanks having lay-flat dimensions of 14 x 14 feet. Later this was changed to a request for two 10,000-gallon prototype tanks, having larger lay-flat dimensions.

Weaving Trials

The smaller size collapsible tank fabrics are usually made from 840 denier high tenacity nylon yarn, for example, Du Pont Type 715, and woven with not less than 28 ends and picks per inch in a plain or basket weave. Breaking strength was to be not less than 350 lb/in.

In order to demonstrate the feasibility of weaving such a fabric in tubular form on a wide loom, a 100-yard warp was beamed and drawn into a 2-1/2 meter wide loom to obtain a flattened tube width of about 6 feet.

In order to facilitate weaving, the warp yarns are coated with a bonding agent called a warp size. Since this fabric was to be coated, a yarn size was developd which could also serve as a tie-coat for the fabric coating to be used. The material used was a proprietary development of Engineered Yarns, Inc., Pawtucket, R.I., who coated the warp yarn.

During the course of the development program, two sizing compounds were used. The first was identified as Engineered Yarns product no. X1602. While it functioned very well as a warp size during the weaving, its ability to provide good coating adhesion when soaked in water was unsatisfactory, as shown in the data of Table III. A second compound, identified by Engineered Yarns product no. X1746, gave somewhat improved coating adhesion, and was used in the final fabric production.

A 2 x 2 basket weave was selected because this would give the best tear resistance. In this construction, 28 x 28 proved to be too open for subsequent handling of the fabric without distortion. Consequently, two tighter constructions were woven, using 38 yarns per inch in the warp and either 38 or 34 picks per inch.

No weaving problems were encountered. Both fabrics wove easily and uniformly giving tubes in which the edge turnaround areas were almost indiscernible (see Figure 3). Properties of these two fabrics are given in Table I.

Table I

Properties of Tubular Woven Fabric Samples

		#1	#2
Count (yarns/inch) Warp x Filling		38 x 38	38 x 34
Weight (oz/yd^2)		11.7	10.7
Tensile Strength (lb/inch)	Warp	429	401
	Filling	418	372

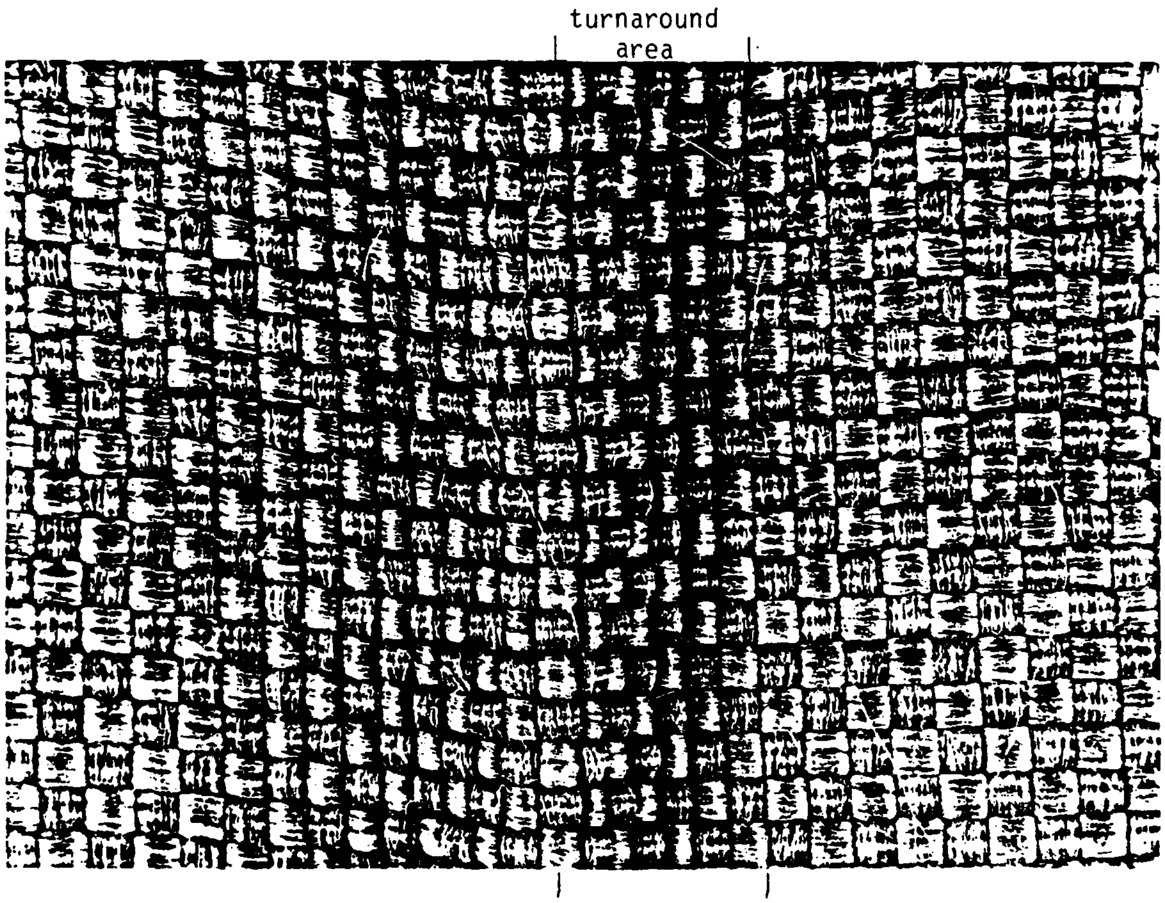

Figure 3. Tubular Fabric Structure Along Edge Turnaround Line

These fabric samples were used in the coating development work, to be discussed later. However, the ease with which they were woven and the total acceptability of their properties were such that it was decided to proceed with weaving a wide enough tubular fabric for manufacture of the two tanks. Fabric #2, woven 38 x 34, was selected as the appropriate construction for the tanks, primarily because its strength was adequate and its somewhat more open construction which, in relation to Fabric #1, led to easier and faster weaving as well as better potential coating penetration.

The final fabric was scheduled to be woven on a 7-1/2 meter wide loom, permitting a maximum woven tube width of about 23 feet. For the 3000 gallon tank, we would have woven a tube having a lay-flat width of 14 feet. In order to increase the size to 10,000 gallons, or as close to that as possible without purchase of a special reed for a wider loom, the fabric was woven at the maximum width on the 7.5 meter loom, which was 23 feet.

The report from Albany International Felt Division describing the weaving of this fabric is contained in Appendix I to this report.

Coating of Wide Tubular Woven Fabric

The coating of a cut length of tubular woven fabric requires special facilities which a flat fabric coating range cannot provide. The tubular fabric must be slid onto cantilevered rolls which are as wide as one dimension of the desired tank, and which can be separated by a distance roughly equal to the other dimension of the tank (see Figure 4). After applying coating on one side, the tube must then be turned inside out on the rolls to coat the other side of the fabric.

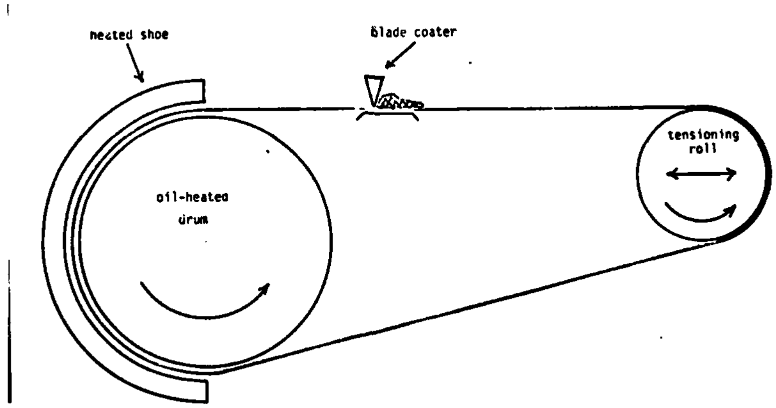

Figure 4. Coater for Tubular Woven Fabric

In most coating ranges the support cannot be removed from one end of the rolls to permit tubular fabric to be slid into place. The range available for coating the tank fabric at the time of this effort has a width of 19 feet. This range is not adequately ventilated to permit the use of solvent-based coating systems, or other systems such as two-component urethanes which may generate noxious or toxic fumes. Thus, we are restricted to the use of latex (water-based) coating systems, and to a coated width of no more than 19 feet. Efforts are continuing to locate a wider coating range suitable for use with two-component urethane systems. This coating range will make it possible to make tanks having capacities of 50,000 gallons or more.

Coating Development

Commercially available latices which might have potential for use in fuel tanks were surveyed and a number of primary candidates tested. Nitriles and urethanes were the only two classes of compound which showed any possibility of providing the needed resistance to fuel in both liquid and vapor form.

The following compounds were studied:

(1) Nitrile Elastomer Latex

The BFG latex systems initially evaluated were Hycar 1571, Hycar 1572, and Hycar 1571X45. They represent both a high and medium acrylonitrile content; Hycar 1572X45 is the most easily heat reactive, has the lowest glass transition temperature, and is the most flexible. The following formulations were made:

	2405-41-A1		2405-41-A2	
	Dry Parts	Wet Parts	Dry Parts	Wet Parts
Hycar 1571 (45%)	100	220	100	220
Zinc Oxide (50%)	5	10	---	---
Butyl Zimate (33%)	2	6	---	---
Cymel Resin 373 (85%)	---	---	5	6
Sulfur (50%)	2	4	---	---

	2405-41-B1 Dry Parts	2405-41-B1 Wet Parts	2405-41-B2 Dry Parts	2405-41-B2 Wet Parts
Hycar 1572 (50%)	100	200	100	200
Zinc Oxide (50%)	4	8	---	---
Butyl Zimate (33%)	1	3	---	---
Cymel Resin 373 (85%)	---	---	5	6
Sulfur (50%)	2	4	---	---

	2405-41-C1 Dry Parts	2405-41-C1 Wet Parts	2405-41-C2 Dry Parts	2405-41-C2 Wet Parts
Hycar 1572X45 (47.3%)	100	211	100	211
Cymel Resin 373 (85%)	---	---	5	6

The Hycar 1571 formulations were too hard; the Hycar 1572 formulations were poor film-formers; and the Hycar 1572X45 gelled too quickly. Modifications were obviously required.

The modification developed for Hycar 1571 follows:

	2405-43-A2-5 Dry Parts	2405-43-A2-5 Wet Parts
Hycar 1571 (45%)	100	220
Cymel Resin 373 (85%) + 29 Water	10	40
Adjust to pH 8.5		
ASE60 + Water	2	4
Harshaw W3057 + Water	2	4

This formulation yielded high film strength (1500 psi), good fuel resistance, but was quite stiff.

	2642-5-A1-2 Dry Parts	2642-5-A1-2 Wet Parts
Hycar 1571 (44.6%)	100	224
Zinc Oxide (50%)	5	10
Sulfur (50%)	2	4
Butyl Zimate (33%)	1	3
Harshaw W3057	1	2
Acrysol GS (25%)	4	16

This last Hycar 1571 formulation (1642-5-A1-2) proved to have good barrier properties, reasonable tensile strength (1200 psi) and was not stiff.

The Hycar 1572X45 formulation modifications led to the following:

	2405-44-C2-3	
	Dry Parts	Wet Parts
Hycar 1572X45 (47.3%)	100	211
Cymel Resin 373 (85%) + 29 Water	5	35
Oxalic Acid (10%)	0.5	5
Acrysol GS (25%)	1	4
Harshaw W3057 + TiO_2 #2101	8	10

However, a tensile strength maximum of 500 psi resulted and the barrier properties were poor.

The Hycar 1572 modifications (the B2 series) had reasonable film properties with good strength and adhesion; but the barrier properties were lacking. However, the following formulation was continuously coated on an endless loop of tank fabric yielding satisfactory strength and 15 lbs/inch initial adhesion.

	2405-47-B2-2	
	Dry Parts	Wet Parts
Hycar 1572 (50%)	100	200
Zinc Oxide (50%)	5	10
Harshaw W3057 (color)	1	2
Cymel Resin 373 (85%) + 29 Water	9.4	40
Acrysol GS	0.75	3

The other modifications that were screened follow:

	2505-44-B2-1		2505-47-B2-6		2505-48-B2-8		2642-1-B2-11	
Parts →	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Hycar 1572	100	200	100	200	100	200	100	200
TiO_2 (2101)			5	5	10	10	9	18
Harshaw W3057	1	2	1	2	1	2	1.5	3
TSPP (5%)					0.75	15	0.75	15
Zinc Oxide							5	10
Sulfur							2	4
Cymel 373	10	12	4	5	7	8	5	12
Acrysol GS	0.5	2	0.5	2	0.75	3	1.5	6
Oxalic Acid			0.5	5				
NH_4Cl					2	10		
Clay					12			

Film strength and limited fuel diffusion properties for the various type formulations are listed in Table II.

Because of the good fuel diffusion properties, the formulation based on Hycar 1571, designated 2642-5-A1-2, was continuously coated on an endless loop of specially primed tank fabric. Table III lists the measured properties of the coated fabric. The physical properties and fuel diffusion appear to be satisfactory; however adhesion is deficient. The best initial adhesion obtained was 10 lbs/inch and 8 lbs/inch after fuel immersion. After water immersion the adhesion dropped to 2 lbs/inch. It was concluded that there is a serious adhesion problem with this nitrile latex system.

Table II

Coating Properties

Forumulations	Strength (psi)	Elongation (%)	Fuel Diffusion Index (oz/sq ft/24 hrs)
X-1162	1760	275	
X-1162 (crosslinked CX-100)	3555	170	0.64
R-962	3500	500	1.0
R-967	4200	500	
A1-2	1200*	330	0.11
A2-5	1500	555	
B1	675	590	
B2-1	1090	600	
B2-6	1135	510	0.94
B2-8	1320	480	0.54
B2-11	1200	660	0.52
C1	510	370	
C2-3	1090	455	
C2-4	925	600	0.56

*62% retained after 14 day fuel immersion; 48% retained after 14 day water immersion.

Table III

Coated Fabric Properties

11.3 oz/sq yd Nylon Tank Fabric
Primed Cord by Engineered Yarns (product no. X1602)
Coating 2642-5-A1-2 (based on Hycar 1571)
Total Weight 41 oz/sq yd (fabric - 11.3; coating 29.7)

Strength, psi,	warp	555 lbs/inch at 37% elongation
	fill	590 lbs/inch at 52% elongation
Puncture Resistance		174 lbs
Tear	warp	87 lbs
	fill	110 lbs
Adhesion		
	initial	8-10 lbs/inch
	after 14 day fuel immersion	7-8 lbs/inch
	after 14 day water immersion	2 lbs/inch
Diffusion Rate Index		0.1 oz/sq ft/24 hours

(2) Other Nitrile Coatings

Hycar 1561, a very high acrylonitrile copolymer by BFG, was also evaluated; but basically it did not make a good coating because the film was too hard and cracked and had inadequate film strength.

(3) Urethane Compounds

Two water borne, air dry urethane polymers made by Polyvinyl Chemical Industries (A Beatrice Chemical Co.) were evaluated. NeoRez R-967 and NeoRez R-962 both made good fabric coatings in terms of abrasion resistance, strength, and adhesion; but fuel diffusion was very high and water resistance was poor. When both materials were further crosslinked using an aziridine, CX-100 (Polyvinyl Chemicals), water resistance improved but fuel diffusion remained high.

A series of water based urethane coatings by C. L. Hauthaway and Sons Corp. were also evaluated. Formulations were: X1121, X1162, X1175, X1186, X1188, X2922. X2922 was unique (very high viscosity) and proved to make an excellent flock adhesive. In addition, it could be mechanically foamed (with the addition of a stabilizer) and proved to be an interesting urethane adhesive, but was completely unsuitable as a fuel tank fabric coating.

All the Hauthaway coatings when applied to tank fabric, contained fine bubbles. Attempts to achieve bubble-free coatings were unsuccessful. C. L. Hauthaway was informed of the problems and they also were unable to obtain a bubble-free coating. Further investigations indicated that the bubbles were inherent to the Hauthaway product and were caused by the emulsifying systems used by Hauthaway.

Nevertheless, the best coating, X1162, was evaluated by continuously coating an endless loop of tank fabric. The resulting product had good physical properties, achieved an 0.28 oz/sq ft/24 hr fuel diffusion rate index, had adequate adhesion, but poor water resistance (strength and adhesion dropped markedly after water immersion).

DuPont Adiprene L-100 urethane was also evaluated. To obtain a form that could be coated (this is a 100% solids system) a heat activated Caytur curative was used. Void-free, multiple pass coatings were achieved but even a 100 mil thick film yielded only a 0.37 oz/sq ft/24 hr fuel diffusion rate index. However, strength, adhesion, fuel and water immersion properties were satisfactory.

Because of the necessity of a water-based system and to achieve a low fuel diffusion index, the coating based on BFG, Hycar 1571, formulation 2642-5-A1-2, is recommended for the next development stage.

A seam adhesive has been found that appears to have satisfactory fuel and water resistance and is designated as: Tycel 7002/Tycel 7202. This is a urethane adhesive system made by Hughson Chemicals. Also, a one part adhesive appears to be satisfactory for bonding the nitrile coating to metal and is designated as: Tycel TA-1107-65A, a moisture cure urethane by Hughson Chemical. Tests on these systems are currently under way.

Appendix I

Endless Weaving of Elastomeric Fuel Tank Fabric

Introduction:

Albany International Felt Division has, for many years, woven endless wet felts for the pulp and paper industry. This endless weaving technology was thought to be applicable to the weaving of endless nylon substrates for use as elastomeric fuel tanks. These endless fabrics can be woven in one large piece thus eliminating the fabrication required using narrow nylon yard goods. The fundamental technique used to weave endless fabrics is to weave two pieces of fabric, one on top of the other, in one loom simultaneously and to maintain a perfect "loom edge" (in weave sequence) as the filling yarn weaves from one layer to the other. This "loom edge" is the key to success in endless weaving. If a fabric has a balanced warp and filling density such as the elastomeric fuel tank fabric, it will have a tendency to narrow in at the loom edge or filling turn-around point. When the fabric narrows in at the loom edge the warp density increases thus destroying the fabric uniformity and also causes reed chafe to the warp yarns. To prevent this phenomena additional equipment is employed to hold out the fabric edges to the required width. A "jacket board" has end tips which come in contact with the loom edges and adjust to reed width via telescopic adjustment. To insert a "jacket board" into the fabric tube and to adjust the "jacket board" tips, a portion of the fabric must be destroyed. The "jacket board" is a viable piece of auxiliary equipment but the external "Dutch temple" serves the same function and can be adjusted external to the fabric tube without damage to the fabric. The "Dutch temple" operates on the principle of a metal sleeve with a slot machined the length of the sleeve. A rod somewhat smaller in diameter rides internal to the sleeve but cannot pass through the slot. The fabric edge passes through the slot in the sleeve around the internal rod and out through the slot again. This sleeve and rod assembly are held by steel framework which is bolted to the breast beam of the loom. For a fabric the size of the elastomeric fuel tank the external "Dutch temple" device was found to be more flexible than the "jacket board." There are no problems encountered through weaving that were related to the "Dutch temple" device.

General Comments:

The nylon fabrics wove exceptionally well once bruised warp yarns were eliminated. A yarn lubricant was used on areas on the fabric where yarn filament damage was experienced. The lubricant was a 5 to 1 mixture of water and soluble oil known as Twitchel. Warp yarn knots caused filament damage when knots would not pass through the reed. The Texo loom used to weave these fabrics employed all 16 harnesses to better distribute warp load to the loom dobby head motion. Fabric density, although high, did not pose any problem in achieving the pick count. The Texo loom is more than adequate for this fabric design.

Fabric Specifications:

Warp Yarn	- 840/149/.5 DuPont nylon coated by Engineered Yarns, Inc.
Filling Yarn	- same as warp
Ends per Inch on Warp	- 72 (36 ends/inch/layer)
Picks per Inch	- 72 (36 picks/inch/layer)
Reed	- 36 dent reed 2 ends/dent = 72 total
Weave	- 2 x 2 basket weave (see Figure A-1)
Reed Width	- 282"
Woven Size	- 46' endless x 22' wide.

Problems Encountered:

(1) Poor spool winding of warp yarn posed problems during dressing of warp. Spools were not wound evenly and had high and low spots.

(2) Excessive knots in warp yarn spools caused yarn breakage in both dressing and weaving. The fine reed density used in both dressing and weaving would not permit a knot to pass through the reed.

(3) Black coating on yarn contaminated the urethane tension roll on the dresser as well as auxiliary rolls.

(4) Examination of yarn coating showed no filament to filament bonding which caused problems through all operations. In the future the coating should act like a sizing in addition to providing a tie coat function.

(5) The black coating of the yarn is not the best color optically. The black color made drawing in the harnesses and reeding in difficult. The black color also made weaving defects difficult for the weaver to see. AIFD used its best weavers for this job.

(6) Because the black coating did not offer filament protection a warp lubricant (Twitchel) was used, where needed, to prevent chafe to the warp yarn. This occurred especially during startup of the warp and at the loom edge.

(7) Due to poor yarn coating all dressing, drawing in, and weaving personnel had to lubricate their hands before handling the yarn.

(8) Yarn coating contaminated everything with which it came in contact. This included all equipment, clothing, and hands. Contamination was cleaned with plain soap and water.

Recommendations:

(1) Develop a better yarn coating that does not contaminate everything it contacts and also provides filament bonding similar to a yarn sizing.

(2) Use pencil bobbins 12" long x 1-3/8" round rather than standard bobbins 12" x 1-5/8" round. Pencil bobbin causes less filling drag.

(3) Use another color for coating. Any color other than black.

(4) After each piece (22') was woven a dobby chain was installed on the head motion which raised each of the 16 harnesses individually and enabled the weaver to see if any warp ends had come out of the bottom cloth.

(5) Specify no knots in warp yarn packages from supplier.

Box 2 Shuttles	Pick	EDGE	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
1 ← 1	M E	X	X						X		X						X		1 Face
2 ← 2	M E	X	X						X		X						X		2 Face
2 → 2	H E		X		X		X	X	X	X	X		X		X	X	X	X	3 Back
2 → 2	H E		X		X		X	X	X	X	X		X		X	X	X	X	4 Back
1 ← 1	M E	X	X		X		X						X		X				5
2 ← 2	M E	X			X		X						X		X				6
1 → 1	H E		X	X	X	X	X		X		X	X	X	X	X		X		7
2 → 2	H E		X	X	X	X	X		X		X	X	X	X	X		X		8
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2 X 2 BASKET WEAVE - ENDLESS
FOR EX-010 ELASTOMERIC FUEL TANK

Revised
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Figure A-1. Fabric Weave